Using the Hottest Particles in the Universe to Probe Icy Solar System Worlds

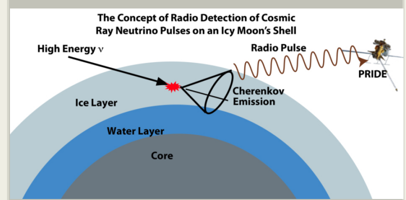
Completed Technology Project (2014 - 2015)

Project Introduction

The proposed instrument, which uses experimental techniques adapted from high energy physics, is a passive receiver of a naturally occurring signal generated by interactions of deep penetrating cosmic ray neutrinos. It could measure ice thickness directly,and at a significant savings to spacecraft resources. In addition to getting the global average ice thickness this instrument can beconfigured to make low resolution global maps of the ice shell. Such maps would be invaluable for understanding planetary features and finding the best places for future landers to explore. The approach and our findings so far are described in our paper in Icarus (Miller, et al., 2012, Icarus 220, 877–888). The basic idea is to use radio receiver technology to detect cosmic ray neutrinos passing through the ice sheet and generating Cerenkov radio pulses (the Askaryan effect). The rate and directional distribution of the detected neutrino interactions will depend upon the thickness of the observed ice sheet. This technology has previously been demonstrated on Antarctic balloon flights by the ANITA neutrino project. In this work we will extend the scope of our original investigation and explore in greater detail the possibility of making low resolution global maps of the ice shells - instead of simply getting a global average ice thickness. In addition, we will improve the fidelity of our initial simulation used to analyze the concept in several important areas in order to more precisely determine the final measurement capabilities of the instrument.

Anticipated Benefits

We have conducted an initial exploration of a concept for a novel and innovative low cost, low power, low mass passive instrument to measure ice depth on outer planet moons, such as Europa, Ganymede, Callisto, and Enceladus. Indirect measurements by the Galileo and Cassini spacecraft indicate that liquid water oceans are likely present beneath the icy shells of such moons (see e.g., the JPL press release The Solar System and Beyond is Awash in Water). This has important astrobiological implications, and the exploration of such moons is a high priority. The formation, structure, and evolution of these planetary objects are subjects of great interest for understanding how the conditions of life can form, and more generally for understanding the formation of these types of moons. The characteristics of the ice layer are important for deriving properties of the oceans underneath, and for planning future probes and determining possible locations for future landers. For example, on Europa the thickness of the ice layer is key to understanding the possible exchange of ocean nutrients with the surface, understanding the mechanism for heating the ocean, and determining whether the ice might be thin enough to allow a future probe to reach the ocean for sampling. Currently, there is no easy way to measure the thickness of ice that could be tens of km deep, as doing so is very challenging given spacecraft size, weight and power resources. The currently favored approach uses a suite of instruments, including a high power, massive ice penetrating radar, to



Concept diagram

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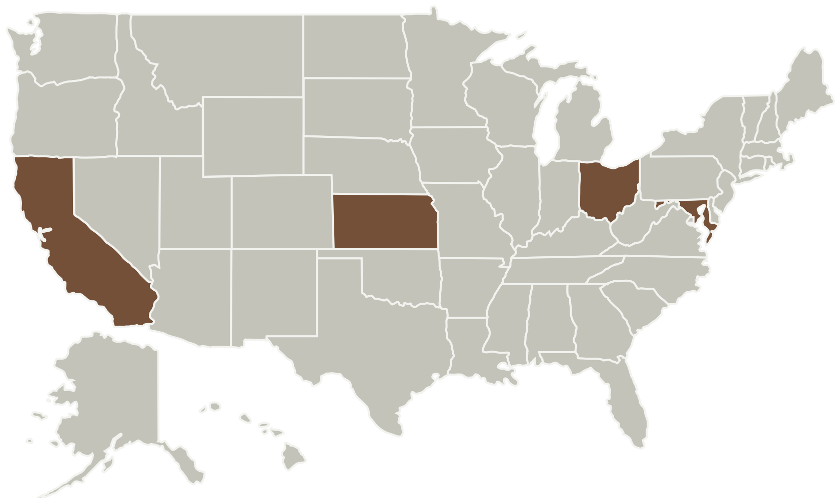
provide constraints on ice thickness. The described proposed instrument, which uses experimental techniques adapted from high energy physics, is a passive receiver of a naturally occurring signal generated by interactions of deep penetrating cosmic ray neutrinos. It could measure ice thickness directly, and at a significant savings to spacecraft resources. In addition to measuring the global average ice thickness this instrument can be configured to make low resolution global maps of the ice shell. Such maps would be invaluable for understanding planetary features and finding the best sites for future landers to explore.

Primary U.S. Work Locations and Key Partners



Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Johns Hopkins University Applied Physics Laboratory (JHU/APL)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

Eric A Eberly

Principal Investigator:

Timothy J Miller

Co-Investigators:

Steven W Barwick
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Robert K Schaefer
Grant K Stephens
Gerald J Patterson
Stuart A Kleinfelder

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Organizations Performing Work	Role	Type	Location
Johns Hopkins University Applied Physics Laboratory(JHU/APL)	Lead Organization	R&D Center	Laurel, Maryland
Ohio State University-Main Campus	Supporting Organization	Academia	Columbus, Ohio
The Lebedev Physical Institute of the Russian Academy of Sciences(LPI RAS)	Supporting Organization	Academia	Moscow, Outside the United States, Russian Federation
University of California-Irvine	Supporting Organization	Academia	Irvine, California
University of Kansas	Supporting Organization	Academia	Lawrence, Kansas

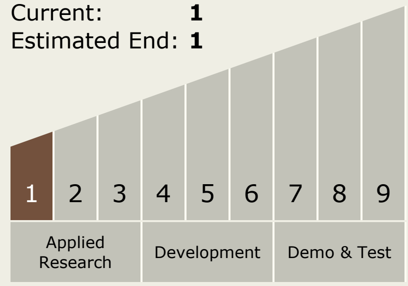
Primary U.S. Work Locations	
California	Kansas
Maryland	Ohio

Project Transitions

July 2014: Project Start

Technology Maturity (TRL)

Start: **1**
Current: **1**
Estimated End: **1**



Technology Areas

Primary:

- TX01 Propulsion Systems
  └ TX01.3 Aero Propulsion
    └ TX01.3.11 Engine Icing

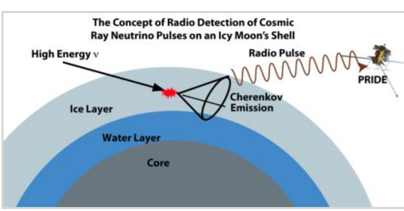
Target Destination

Others Inside the Solar System

April 2015: Closed out

Closeout Summary: We present results of our Phase 1 NIAC Study to determine the feasibility of developing a competitive, low cost, low power, low mass passive instrument to measure ice depth on outer planet ice moons, such as Europa, Ganymede, Callisto, and Enceladus. Indirect measurements indicate that liquid water oceans are likely present beneath the icy shells of such moons (see e.g., the JPL press release The Solar System and Beyond is Awash in Water), which has important astrobiological implications. Determining the thickness of these ice shells is challenging given spacecraft SWaP (Size, Weight and Power) resources. The current approach uses a suite of instruments, including a high power, massive ice penetrating radar. The instrument under study, called PRIDE (Passive Radio Ice Depth Experiment) exploits a remarkable confluence between methods from the high energy particle physics and the search for extraterrestrial life within the solar system. PRIDE is a passive receiver of a naturally occurring radio frequency (RF) signal generated by interactions of deep penetrating Extremely High Energy (> 10^18 eV) cosmic ray neutrinos. It could measure ice thickness directly, and at a significant savings to spacecraft resources. At RF frequencies the transparency of modeled Europan ice is up to many km, so an RF sensor in orbit can observe neutrino interactions to great depths, and thereby probe the thickness of the ice layer. Prior to our NIAC Phase 1 study, we analyzed the capability of PRIDE under the assumption of pure cold Europan ice, which we describe in [9]. Our goal in Phase 1 was to evaluate the promise of the concept in more realistic conditions. We made considerable progress in multiple areas: -We implemented several possible Europan ice models in detail, including impurity content and depth-dependent temperature and attenuation length. We identified a useful range of likely ice models for which event rates are in the hundreds or more per year and for which ice sheet depth measurement capabilities exist for thicknesses up to tens of km. -We adapted three existing, higher fidelity simulations used in the EHE astrophysics community by the ANITA, RICE, and LORD projects to the PRIDE application, and compared results to validate our expected event rates and other measurables. -We implemented models for several other ice moons: Ganymede, Callisto, and Enceladus, and implemented models for both Polar and Equatorial ice. We found that PRIDE is most promising for Europa and Enceladus, and that notably different depth measurement capabilities exist for polar vs equatorial ice due to colder polar temperatures. -We implemented a model of local water inclusions within ice sheets. We found that a variety of local water inclusions for both Enceladus and Europa should be detectable, but should not significantly compromise our ice depth measurements -We analyzed new observables to determine their ability to resolve ice depth independently of overall event rate, including event size, zenith angle to surface exit point and cascade location in the ice, and frequency content vs depth. We found promising results for some observables. -We performed an initial analysis of cosmic ray events, which are expected to be a major background for PRIDE. We found potential measurable quantities to distinguish cosmic ray events from neutrino events. -We leveraged existing efforts on developing low power digitizer technology to develop a chip applicable to PRIDE with 2 Gs/s rate, 1.3 GHz bandwidth, and expected favorable radiation hardness properties, which uses only 32 mW per channel, ideal for a deep space mission. -We established an MOU with Russian EHE neutrino researchers at the Lebedev Physical Institute. They are now part of the PRIDE collaboration via their own funding, and have contributed modifications to and analysis with the simulation they developed for the LORD EHE neutrino project.

Images



Concept of Radio Detection of Cosmic Ray Neutrino Pulses on an Icy Moon's Shell
Concept diagram
(https://techport.nasa.gov/image/102306)

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html